A brief review on tsunami early warning detection using BPR approach and post analysis by SAR satellite dataset

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Abstract

Tsunami early warning systems have provided to be the extreme importance after the tsunami that hit Japan in March 2011. This research article presents a case study based on the tsunami detection using Bottom Pressure Rate (BPR) measurement and the post the analysis using the SAR datasets. A final decision based system using BPR has been studied to carry out the measurements of tsunami wave parameters. SAR based study has also been carried out for the post tsunami studies. Wiener filters are utilized to remove the speckle noise presents in imagery. Future scope of this work has also been proposed.

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Keywords: Remote sensing; Tsunami damage detection; Epicenter; BPR.

1. Introduction

The early detection and warning systems have shown and proven an ultimate importance, especially after the destructive tsunami that hit Japan in March 2011. The purpose of this research is to notify and enhance the existing tsunami results for the detection and early warning prediction with the suitable accuracy [8].

In the Pacific Ocean, a basin-wide tsunami occurred in 1960. The main cause of this generation was by the gain Chilean earthquake, which was recorded as magnitude of 9.5 over the Richter scale. Tsunami caused more than 1500 casualties over the Chilean coast. Following this mega disaster, a team has formed known as Tsunami commission by IUGG and they develop tsunami warning system for the scientific studies and investigation of the tsunamis by means of the underwater explosions.

Furthermore, December 26, 2004 Indian Ocean tsunamis was again the worst disaster in the history and was caused by giant Sumatra-Andaman earthquake with magnitude of 9.3 devastated the shores of Indian Ocean [17,19,18].

International coordination group was initiated and formed by Intergovernmental Oceanographic Commission (IOC) under United Nations Educational, Scientific and Cultural Organization (UNESCO) after the huge 1960 Chilean Tsunami in 1960. Again in 1965, another coordination group which is known as International Tsunami Information Centre (ITIC) with the support from United States of America, National Oceanographic and Atmospheric Administration (USA-NOAA). The International Coordination Group for Tsunami Warning Systems (ITSU) in Pacific was also formed and established under IOC [14].

Once the tsunami waves generated from the deep water and runs up towards the coastal regions, it’s a difficult task to prevent the life. In order to resolve these kinds of problems, early warning systems are implemented in operation to analyze and produce the results to disaster team. The basic concepts of such systems is to detect any kind of unusual seismic activities under water and automatically judge whether the seismic activity has been generated from the cause of earthquake or some other reason. After this process, bulletins
must be issues to the disaster’s authority in order to take up the appropriate action [3,5].

Tsunamis, a critical natural menace, have the power to source great destructions with damage of lives within moments on shores. Any place having a huge water bodies, large lakes even, can cause a tsunami. From sources of history and scientific observations, the occurrence of Tsunamis can be in any large seas of the world, with almost 85% of tsunamis happening in the Pacific region, causing damage within hours across a complete ocean basin. Thereby, devastating tsunamis happen in geologically less lively oceans like the Atlantic, the Indian Ocean or the Mediterranean [10].

Since the seismic activity of tectonic plates cause tsunami, they are often found in the Earth’s most restless fields around the Pacific Rim along the "Pacific Ring of Fire", a region of high tectonic activity. According to statistics, 17 tsunamis occurred, in the Pacific, in between the year 1992 and 1996, taking nearly 1700 lives.

Numerous reports of newspaper along with various movies about undersea earthquakes and meteor inflicted tsunamis have bestowed to public awareness of the threat. The outcomes of tsunami can be catastrophic at times, for example, 2004 tsunami in Indian Ocean, the entire Indian Ocean was propagated and caused immense destruction to at least 12 countries. They have the strength to knock down infrastructures, crush and flip vehicles, lift giant rocks, demolish houses and cause failures of local/regional/international communication network and emergency response systems, causing damage worth of millions or even billions of dollars. Some of which could not even be addressed for months. They result in decline of any economy. In order for detecting the tsunamis there is a need to determine the magnitude and epicenter of the earthquake.

One way to do so, is to verify the earliest arrivals, the time of arrival and the wave amplitude of the tsunami, for which a former understanding of modeled propagation of the tsunami, is required by the system. The system is then capable to respond to a warning. Such as, system subscribers will reliably acquire a telephonic warning, as and when a threatening tsunami is unrolled [1].

However, the large scale of tsunami destruction makes it hard to comprehend total tsunami impact in the whole Ocean. Latest developments of technologies of remote sensing crush many problems and guides to detecting the elaborated characteristics of tsunami detriment. Another way to do so, as many researches propose, is an overview in developing a way to look for and discover the impact of tsunami damage by integrating numerical modeling, technologies of GIS and remote sensing. Section of this method is carried out to few tsunami event, such as, in the year 2007, on Solomon Island, tsunami caused by earthquake, to find the affected regions and know the structural destruction, using the above method and the analysis of satellite imagery with high-resolution optical.

Presently tsunami watch systems are built on computer programs of modeling which notify against the likelihood of the impacts of earthquake-originated tsunami, and try to forecast their strength along with their arrival times vs. location based on the earthquake properties. These models of computer consist ocean-scale bathymetry and geometries of coastline, with the input criterions modernized by ocean base pressure as the wave of tsunami moves over after a potentially threatening earthquake. A protocol lives for the quick dissemination of seismic data and tsunami model notifications between alien governments but there is no system for local discovery of a real incoming wave having a valuable alerting power.

Another process describes the sea level tide-gauges at coastal positions, nearer to the epicenter, able to convey vital quantitative data for locations further downstream, as in the year 2011, in Japan, the tsunami signals were detected through numerous HF radars all around the Pacific Rim with correct outcomes from sites in Japan, US and Chile. An empirical way for the automatic notification of a tsunami based on pattern-recognition in time series of tsunami-generated current velocities, using information taken by fourteen radars on the coasts of Japan and USA. Presently the HF radar systems works without break from many coastal locations around the globe, observing the currents on the surface of the ocean and waves to distances up to 200km from shore [7,13,12]. Basically the tsunami arrival and detection researches are limited but the post processing has been carried in some of the literatures using satellite image analysis for the affected area, tsunami damage level classification using image processing and manual techniques.

The main components for an end-to-end system of tsunami are to yield real-time surveying, seismic and tsunami activities alert, punctual decision production and advisories, and dissemination of warnings and information.

2. Scientific advancements

Most of the current tsunami under water seismological algorithms has been developed since the 1960s when the giant Chilean earthquake generated in Pacific Ocean. Plate tectonic theory was also introduced in the same year, numerous mathematical models of earthquake source were developed to relate the seismic moment and size of the fault. For an observational sides, various tide gauge sensors, seismic networks was also deployed in 1960s. In 1970s, using the obtained theories and observed datasets, fault attributes of the larger or smaller earthquake studies have been carried out. The magnitude moment scale which is well known as Richter scale was also introduced. Theoretical and computational developments made to estimate and compute the seafloor shift, fault sizes and tsunami wave propagations models on the actual bathymetry. In 1980s, seismograms have been recorded digitally, which improved the data quality and reduces the processing times. The large scale tsunami propagation models were also employed and studied in this decade and it became more popular. The developments and advancements of computer networking have made it possible and reliable to carry out the researches in seismic wave analysis and real time measurements of the tsunami wave parameters. Furthermore, the tsunami hazard development tools have also been
implemented and discovered to analyze the seismic activities [16,17].

In the present era, the globally observed seismological and sea-level datasets are available within the minutes through the internet [21]. Using these datasets and information’s, more tsunami studies could be carried out in a very short duration of time. Numerous scientific reports and research articles have been published regarding the 2004 tsunami earthquake [22]. Here, we only refer the special issues of some of the reputed scientific journals in which most of the seismological aspects of tsunami and earthquakes are explained [20].

As under the discussion and part of the tsunami working group, the tide gauge data was collected and compiled about 40–50 tide gauge records in to region of Indian Ocean to analyze maximum amplitude and spectral components. Sea-level monitoring of the oceanographic activities have been developed known as Global Sea Level Observation System (GLOSS) and is located in Australia, The pacific and Atlantic oceans recorded the 2004 tsunami [16].

Tsunami execution and propagation was also measured on hydrophones or seismometers in which the analysis have been carried out to provide a wide range of time of arrival about 90 to 3000s. The aspect of Global Positioning Systems (GPS) measurements of tsunami and its surveys have also been carried out this research categories based on the societal responses [9,15].

The real-time observations and monitoring of a tsunami have been limited to deep-water pressure-sensor observations of variation in the sea level changes. The coastal based radar monitoring systems are implemented in various countries to detect the tsunami wave’s arrival near to the coast and to analyze and present the report to the disaster management team for the quick and sudden action to save various lives. Belinda Lipa et al. [30] have suggested an empirical model for the detection of the initial arrival of a tsunami, and demonstrate its use with results from data measured by fourteen high frequency radar sites in Japan and USA following the magnitude 9.0 earthquakes off Sendai, Japan, on 11 March 2011. The distance offshore at which the tsunami can be detected, and hence the warning time provided, depends on the bathymetry: the wider the shallow continental shelf, the greater this time. Arrival times measured by the radars preceded those at neighboring tide gauges by an average of 19 min (Japan) and 15 min (USA) The initial water-height increase due to the tsunami as measured by the tide gauges was moderate, ranging from 0.3 to 2 m. Thus it appears possible to detect even moderate tsunamis using this method. Larger tsunamis could obviously be detected further from the coast. We find that tsunami arrival within the radar coverage area can be announced 8 min (i.e., twice the radar spectral time resolution) after its first appearance. This can provide advance warning of the tsunami approach to the coastline locations.

3. Proposed detection and warning systems

In this article, we study and analyze the tsunami caused by earthquakes which can further be defined as a sudden disturbance of tectonic plates on the earth core. A system must be employed in universe which correlates the relation between sudden tectonic plate’s displacements and propagation of tsunami waves from deep to coastal regions of the wave propagation [2,4].

Tsunami warning systems starts with the monitoring of seismic events and corresponding wave patterns and determining the earthquakes magnitude and epicenter, then further it detects the tsunami waves. Such system detects the propagation of tsunami waves before it strikes on shoreline [6].

A comprehensive tsunami detection and warning system consists of:

1 Seismic data, marine data collection using in-situ method or satellite remote sensing imageries
2 A secured sea to ground surface and space based telecommunication network.
3 An observing system which is effectively a virtual network known as Global Seismic Network (GSN), to measure and record all seismic vibrations
4 Regional satellite or other telecommunication based network to provide efficient budget link analysis
5 Additional notification system through mobile based dissemination technique to support the government for the quick action.

Table 1 indicates the bulletin content based upon the decision about tsunami generation risks. In general it depicts that the local tsunamis effects are within 100 km of the epicenter, regional tsunamis are limited to 100 km of epicenter and ocean-wide tsunamis are across the entire ocean basin.

The case study of Japan tsunami is presented in this paper, and the acquired datasets for the same is proposed in Fig. 1.

The further step of the detection process is to obtain bottom pressure recorder (BPR) Measurement \(h_d\). This information is required to measure the expected run-up of the tsunami waves towards the coast from deep water. Furthermore, depends on the flow chart mentioned in Fig. 2, the bulletins are generated and sent the warning to the concerned authorities using e-mail for emergency purpose. The measurement is used to estimate the expected run-up as per the equation provided in Eq. (1) [23].

\[
\frac{h_s}{h_d} = \left(\frac{H_d}{H_s}\right)^{1/4}
\]
The bottom pressure recorders play the important role to find and detect the actual cause of the tsunami generation point. It can be seen that if BPR is greater or equal to 0.03 m, the tsunami run-up starts. If the magnitude reaches more than 2 m, the warning is to be issued to the concerned authority for the further action. Hence, if BPR design should be so accurate in such a way that it should provide the accurate threshold command values so that the quick action can be taken. The last and final step of the tsunami detection is to obtain the sea level fluctuation recorded by the tide gages located at the shore line and the actual run-up and the maximum wave run-up inundation can further be estimated using the mathematical relationship as mentioned in Eq. (2).

$$H_{\text{max}} = 2.83h_3^{1.25}\cot B$$  \hspace{1cm} (2)

$B$ is the slope of the seabed (in degrees)

Finally the bulletin is to be circulated depends on the decision provided. The actual and acquired run-up values should be matched for the further validation. The updates about the confirmation or cancellation are done based on the chart as illustrated in Fig. 3.

3. SAR image processing

The remote sensing tools are now a day on demand to analyze the tsunami affected regions. One of the important and sophisticated well known sensor Synthetic Aperture Radar (SAR) sensors can be used to observe the datasets. SAR satellite sensor has been designed and, partially, put into operation, leading to an important breakthrough in Earth Science studies. The common characteristics of such new systems are, indeed, a reduced revisit time (as short as a few days) and, in most cases, an improved spatial resolution (as
small as a few meters), providing scientists with unprecedented data for the mapping and monitoring of natural and human-induced hazards [12-15]. At present due to lack of the datasets, we could not able to show how the SAR images appear for tsunami affected region. The simulation has been carried out in MATLAB interface. A Wiener filters can be used to enhance SAR image by removing the speckles and further post tsunami analysis can be carried out using image processing technique. Wiener filter that is especially suitable for speckle and noise reduction in multilook synthetic aperture radar (SAR) imagery. The proposed filter is nonparametric, not being based on parametrized analytical models of signal statistics. Instead, the Wiener-Hope equation is expressed entirely in terms of observed signal statistics, with no reference to the possibly unobservable pure signal and noise. This Wiener filter is simple in concept and implementation, exactly minimum mean-square error, and directly applicable to signal-dependent and multiplicative noise. We demonstrate the filtering of a genuine two-look SAR image and show how a no negatively constrained version of the filter substantially reduces ringing [28]. As illustrated in Fig. 4, the images are mapped into black and white binary, where white region represented the damaged fields. A pixel differential rule is applied between the final obtained image and enhanced image, resultant of both provides the black region which indicates unaffected fields. Once these images resulted out, percentage damage can be determined.

A very few examples of detection, determination, and evaluation of the damaged areas affected by the March 11, 2011 earthquake and tsunami in east Japan. Due to very limited time and resources, we used only conventional analysis methodologies; in spite of this limitation, we have been able to show the very promising potential of PoSAR in disaster observation, especially for scattering mechanism analysis, compared to conventional single polarization SAR and optical remote sensing. Detection of damaged areas after a disaster can be done using only a single PoSAR observation. This is a great advantage compared to the widely used techniques of SAR interferometry. In particular, this advantage is significant for airborne PolSAR systems, which usually do not have archived data sets. In addition, though the resolution of the spaceborne ALOS/PALSAR full polarimetric mode is not fine enough to identify each target, it could provide largescale monitoring and understanding of the damaged area by revealing the polarimetric scattering mechanisms on the whole. Finally, observations of paddy fields demonstrated the possibility of quantitative evaluation of the flooding effect using PolSAR images [24].

The use of full polarimetric synthetic aperture radar (PolSAR) images for tsunami damage investigation from the polarimetric viewpoint. The great tsunami induced by the earthquake of March 11th, 2011, which occurred beneath the Pacific off the northeastern coast of Japan, is adopted as the study case using the Advanced Land Observing Satellite/Phased Array type L-band Synthetic Aperture Radar multitemporal PolSAR images. The polarimetric scattering mechanism changes were quantitatively examined with model-based decomposition. It is clear that the observed reduction in the double-bounce scattering was due to a change into odd-bounce scattering, since a number of buildings were completely washed away, leaving relatively a rough surface. Polarization orientation (PO) angles in built-up areas are also investigated. After the tsunami, PO angle distributions from damaged areas spread to a wider range and fluctuated more strongly than those from the before-tsunami period. Two polarimetric indicators are proposed for damage level discrimination at the city block scale. One is the ratio of the dominant double-bounce scattering mechanism observed after-tsunami to that observed before-tsunami, which can directly reflect the amount of destroyed ground-wall structures in built-up areas. The second indicator is the standard deviation of the PO angle differences, which is used to interpret the homogeneity.
reduction of PO angles. Experimental results from after- and before-tsunami comparisons validate the efficiency of these indexes, since the built-up areas with different damage levels can be well discriminated. In addition, comparisons between before-tsunami pairs further confirm the stability of the two polarimetric indexes over a long temporal duration. These interesting results also demonstrate the importance of full polarimetric information for natural disaster assessment [25].

A quick response to a large-scale natural disaster such as earthquake and tsunami is vital to mitigate further loss. Remote sensing, especially the spaceborne sensors, provides the possibility to monitor a very large scale area in a short time and with regular revisit circle. Damage ranges and damage levels of the destructed urban areas are extremely important information for rescue planning after an event. Rapid mapping of the urban damage levels with synthetic aperture radar (SAR) is still challenging. Compared with single-polarization SAR, fully polarimetric SAR (PolSAR) has a better potential to understand the urban damage from the viewpoint of scattering mechanism investigation [26].

The great earthquake and tsunami occurred in March 2011 at Japan, the various parameters have been analyzed and resulted out such as the marine debris in the region of Japan coastal area which contains the post analysis activity using SAR datasets over the various processing cycle of the satellite movements [27]. Earthquake & Tsunami of 2011, the number of confirmed deaths is 15,891 as of April 10, 2015, according to Japan’s National Police Agency. Most people died by drowning. More than 2500 people are still reported missing.

The major outcomes of the analysis of the COSMO-SkyMed (CSK) synthetic aperture radar (SAR) observations of the area hit by the 2011 Japan tsunami are presented. The height of the tsunami waves was such as to cause a widespread inundation of the coastal area. The SAR acquisitions have been performed on March 12 (i.e., one day after the tsunami occurred) and March 13, 2011 in interferometric mode, so that not only the information on the intensity of the radar signals, but also the complex coherence has been used. The interpretation of the available data has allowed us to detect the flooded areas, as well as the receding of the floodwater from March 12 to March 13, 2011 and the presence of the debris floating above the water surface. Moreover, thanks to the high spatial resolution of the CSK images, the presence of floodwater in some urban areas in the Sendai harbor has been revealed by exploiting the information on the coherence [29]. Since tsunamis readily manifest themselves as Sea Level Anomalies (SLA) it’s necessary that one satellite overflies the wave almost immediately after it originates. The presence in orbit of several satellites (constellation), instead, allows to improve the frequency of observation and accordingly to have a better possibility in surveying the phenomenon as soon as it occurs. It is worthwhile to remember the ac-

![Original image](Image)

Fig. 4. Tsunami post damage extent analyses [28].
complishment of COSMO-SkyMed (Constellation of Small Satellites for Mediterranean basin Observation) satellite constellation, the first global constellation for Earth Observation. COSMO-SkyMed data can be used to exploit the most advanced remote sensing technology with the four SAR satellites. The satellite constellations would provide more timely and comprehensive data and the ability to support disaster management and information on the evolution of disaster areas.

4. Conclusions

In this article, we carried out a case study of existing tsunami system for the detection and monitoring. A decision based matrix has been prepared to provide the early warning issues based upon the bottom pressure rate measurements. The model was then followed up by the enhancing SAR image processing techniques with the removal of speckle noise using wiener filters. The filters are more suitable for the post tsunami analysis. For the future work, we could propose the improving communication network using the fiber optics microwave cables in the ocean for the selected region. The real-time monitoring can be observed based on the data acquisition techniques to provide BPR to the coastal based radars.

References